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Emissions of Metals and Organics from Municipal Sewage Sludge Incinerators under Steady State and Transient Conditions Preliminary Results

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16. ABSTRACT

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EMISSIONS OF METALS AND ORGANICS FROM MUNICIPAL SEWAGE SLUDGE INCINERATORS UNDER STEADY STATE AND TRANSIENT CONDITIONS - PRELIMINARY RESULTS

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ABSTRACT

Toxic metal and organic compound emissions from municipal sewage sludge incineration have recently become of interest to EPA regulatory efforts as part of reviewing available sewage sludge disposal options. Existing data on metals emissions from these incinerators show a high degree of variability, with insufficient operating documentation to allow adequate data interpretation. Little data on organics have been obtained. The extent to which data already collected may represent long-term emissions from sewage sludge incineration is also questionable. This is due to frequent occurrence of transients caused by changes in operating conditions, e.g., feed rate changes, feed composition changes, and equipment malfunctions, that permit, however, continuing operation of the incinerator. Emissions are expected to be higher during these transients but the majority of existing data have been collected under relatively steady-state system operation at optimum conditions. Normal operation over the long term is a combination of steady-state and transient operation.

This paper presents preliminary results from the EPA test program having the three following major objectives: (1) collecting data that allow a comparison of metals and organic compound emissions during steady-state and transient incinerator operation, (2) evaluating scrubber removal efficiencies for specific compounds, and (3) establishing cause and effect relationships between incinerator operating conditions and emissions. The technical approach first involved selection of appropriate test sites. Three sites with multiple hearth incinerators and one site with a fluidized bed incinerator were selected. Sampling and analysis plans were then prepared for the overall project and for each specific site. This paper concentrates on the first two sites where preliminary results were available. Both of the first two sites tested have multiple hearth incinerators burning a mixture of primary and secondary sludge. Site I has an impingement scrubber only for particulate emission control. Site 2 has a venturi followed by an impingement scrubber. At both sites, tests were performed during steady-state operation and during transient operation.

The preliminary results of the emission tests at Sites 1 and 2 show that metals emissions per gram of sludge feed were similar or slightly higher for Site 1 versus Site 2. This could be due to the difference between the particulate control devices at the two sites. Emissions of lead per gram of total particulates appears to increase with increasing furnace temperature. Scrubber removal efficiencies at Site 2 (where both inlet and outlet data were available) were 95 percent for total particulate and 68 to 91 percent for individual metals. Volatile organic emission levels were similar to metals emissions on a mass basis. Site 1 emissions were slightly higher than Site 2. Some of the volatile organic emissions appear to be products of incomplete combustion.

Differences in long-term average values were seen between steady-state and transient operation but do not appear to be very significant at this preliminary stage of data analysis. It must be emphasized, however, that this is based on a very gross analysis that may contain self-compensating effects. We doubt that this will be the final word on transients. More detailed resolution and analysis of the data is planned in order to try to determine the exact nature of the effects of various transients on incinerator emissions, and to estimate the impacts of prolonged operation away from optimum steady-state.

INTRODUCTION

The Office of Water Regulations and Standards is in the process of developing regulations covering the management of municipal sewage sludge. These regulations are being developed under the Clean Water Act (Public Law 92-500). The development of these regulations is a result of the recommendation of an EPA Sludge Task force, established in 1982, that the Agency develop a comprehensive technical regulatory program for sludge management under Section 405(d) of the Clean Water Act. A more detailed discussion of the overall sludge management regulations has been previously presented at the National Conference on Municipal Sewage Treatment Plant Sludge Management[1].

One of the sludge management options being covered by these regulations is incineration. When sludge is incinerated, the primary pathway for exposure to potentially toxic pollutants is inhalation of air emissions. Ash disposal was eliminated as a potential pathway because the incinerator ash is adequately controlled under the Resource Conservation and Recovery Act (RCRA)[1]. The effluent streams from the wet scrubbers used to control air emissions are typically recycled to the front end of the wastewater treatment plant[1].

In order to evaluate the health risks from sludge incineration, data on air emissions are required. The existing data base on air emissions from sewage sludge incinerators had two major deficiencies. First, previous emission tests were performed for short periods of time and during periods of best operation when emissions are likely to be at a minimum. Sewage sludge incinerators can experience a significant number of transients caused by changes in operating conditions. Data obtained during best operation may not be representative of actual long term emissions. Results from previous emissions tests are also highly variable, with little data documenting system operating conditions.

A second deficiency is that the current data base contains very little data concerning emissions of organic compounds. In a multiple hearth incinerator, the flue gas from the combustion hearths passes through the upper hearths in order to dry sludge entering at the top.

This design could potentially cause volatile organic compounds in the sludge to be carried out of the incinerator without being combusted. In addition, there is some evidence that any organic compounds in the scrubber water may be stripped by the flue gas and emitted to the atmosphere.

The primary goal of this project was to gather emissions data to supplement the existing data base and eliminate some of its current deficiencies. The specific objectives of this project are as follows:

(1) determine long-term emissions over a range of operating conditions;

(2) develop long-term and short-term emission rates relating stack emissions to sludge composition;

(3) determine if short-term emissions data taken during periods of best operation can be used to accurately approximate long-term emissions;

(4) determine the efficiency of wet scrubbers in removing metal and organic emissions; and

(5) develop cause and effective relationships between incinerator operation and emissions.

TECHNICAL APPROACH

Selection of appropriate test sites was an important part of meeting the program objectives. A list of sites was compiled from five previous Radian/EPA studies. These test sites were then contacted by telephone for an initial screening. Site visits were then performed to select a total of four test sites. Site selection focused on multiple hearth incinerators because this is the most common type currently used. Ultimately, three multiple hearth incinerators and one fluidized bed unit were selected to allow a comparison in volatile compound emissions. The general characteristics of these four sites are shown in Table 1. Preliminary results from the first two sites will be discussed later in this paper.

After site selection was completed, a test program was designed to meet the program objectives. Specific compounds and metals of interest are listed in Table 2. Test matrices were developed for each site on the basis

TABLE 1. GENERAL CHARACTERISTICS OF THE SEWAGE SLUDGE MULTIPLE HEARTH INCINERATORS SELECTED FOR TESTING

SITE	FURNACE TYPE	CONTROL DEVICE	SAMPLING LOCATION
1	Multiple Hearth	Impingement wet scrubber	Stack
2	Multiple Hearth	Venturi/impingement wet scrubber	Control Device inlet and stack
3	Fluidized Bed	Venturi/impingement wet scrubber	stack
4	Multiple Hearth	Venturi/impingement wet scrubber	Control Device inlet and stack

TABLE 2. SPECIFIC ELEMENTS AND COMPOUNDS OF INTEREST FOR SEWAGE SLUDGE INCINERATOR TESTING

METALS

Arsenic
Beryllium
Cadmium
Chromium
Lead
Nickel

VOLATILES

Acrylonitrile
Benzene
Carbon Tetrachloride
Chlorobene
Chloroform
1,2-Dichloroethane
Trans-1,2-Dichloroethane
Ethylbenzene
Ethylene Oxide
Methylene Chloride
Tetrachloroethylene
Toluene
1,1,1-Trichloroethane
Trichloroethylene
Trichlorotrifluoroethane
Vinyl Chloride

PCBs and PESTICIDES

Aldrin
Chlorodane
Dieldrin
PCB-1242

PCBs and PESTICIDES (Cont'd)

PCB-1254
PCB-1221
PCB-1232
PCB-1248
PCB-1260
PCB-1016

SEMI-VOLATILES

Acid Compounds

2-Chlorophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
2,6-Dinitro-o-cresol
2,4-Dinitrophenol
2-Nitrophenol
4-Nitrophenol
p-Chloro-m-cresol
Pentachlorophenol
Phenol
2,4,6-Trichlorophenol

Base/Neutral Compounds:

Benzo(a)pyrene
bis(2-ethylhexyl)phthalate
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Perchloroethylene
1,2,4-Trichlorobenzene

of the expected emission characteristics, the acceptability of scrubber inlet sampling locations, and the resources available for the project.

A Quality Assurance Project Plan detailing sampling and analytical methods was written and site-specific test plans containing test matrices and site specific details regarding test locations, and sampling times, etc. were prepared. Reference EPA or state-of-the-art test methods were used for all critical measurements. Results from each test site will be documented in separate test reports and a final engineering analysis report will be prepared to compare data from each site.

PROCESS DESCRIPTIONS

Incinerator and sludge characteristics for the first two test sites are presented in Table 3. Both are multiple hearth incinerators which fire a blend of primary and secondary sludge. The sludge at Site 1 is conditioned with lime and ferric chloride prior to dewatering by vacuum filtration. At Site 2, the blended sludge is conditioned with polymers and dewatered using centrifuges. Site 1 has a 3-tray impingement scrubber and uses a mixture of effluent from primary and secondary treatment for scrubber water. This scrubber type is commonly found on incinerators built prior to the initial new source performance standards (NSPS) for sewage sludge incinerators promulgated by EPA on March 8, 1974. Site 2 has a venturi followed by a 3-tray impingement scrubber and a mesh type demister. The scrubber water for this site is from secondary treatment effluent only. This venturi/tray scrubber combination is typical of newer incinerators built since the NSPS went into effect. Results of sludge analyses for the two sites are presented in Table 4.

Table 5 presents the site specific sampling matricies. At Site 1, testing was only performed at the scrubber exhaust. At Site 2, simultaneous tests at the inlet and outlet of the venturi/tray scrubber were performed to more accurately assess scrubber efficiencies on metals and organic compound emissions. At both sites, tests were performed during periods of best operation (defined as steady-state tests), and during more normal or operation that included typical transients. At site 1, normal operation

TABLE 3. INCINERATOR AND SLUDGE PARAMETERS

Design Parameter	Site 1	Site 2
Incinerator		
1. Manufacturer	Nichols	Hankin Environmental Systems
2. Number of Hearths	6	8
3. Maximum design sludge feed rate, wet tons per hour	7	9
4. Bottom ash production lb/hr	1,053 0,175	1,296 (typical) 1,800 (maximum)
5. Auxiliary fuel		
- Primary - Backup	Natural Gas	Natural Gas Diesel
Sludge Feed		
1. Sludge type	Conditioned and dewatered primary and secondary sludge	Conditioned and dewatered primary and secondary sludge
2. Solids, content, percent	16 to 20	18 to 25
3. Volatiles content, percent of dry solids	50 to 70	50 to 70
Control Device		
1. Type	3 tray impingment wet scrubber	Venturi/3 tray impingement wet scrubber
2. Scrubber pressure drop, in W.C.	7 - 11	25 (For Venturi, scrubber, and demister combined)

TABLE 4. ANALYIS OF SLUDGE SAMPLES
COLLECTED DURING TESTING

Parameter	Site 1	Site 2
% Solids[a]	16.4	20.4
% Volatiles[a] (dry basis)	57.2	66.4
Heating value[b] MJ/kg	2,620[b]	4,080[c]
Metals Concentration, ug/g[d] (dry basis)		
Arsenic	ND	6.1
Beryllium	0.7	0.4
Cadmium	2.9	8.8
Chromium	213	82
Lead	98	99
Nickel	19.4	87
Proximate Analysis[e]		
% Moisture	85.6	79.5
% Ash	5.2	7.4
% Volatile Matter	7.3	10.7
% Fixed Carbon	1.8	2.4

[a]Average of all samples collected during testing. These samples were analyzed at host site laboratory.

[b]Average of three samples collected on different days.

[c]Average of seven samples collected on different days.

[d]Average of sludge samples collected during metals testing.

[e]Based on analysis of a single sample.

TABLE 5. TEST PROGRAM SAMPLING MATRIX FOR SITES 1 AND 2

Incinerator Operating conditions	Flue Gas Samples[a]		Solid/Liquid Samples[b]			
	Control Device Inlet[c]	Control Device Outlet	Sludge Feed	Ash Discharge	Scrubber Water Influent	Scrubber Water Effluent
Site 1						
Steady-State		-M12S (3 runs)	x			
Normal - Primary/Secondary Effluent to Scrubber		-M12L (3 runs)	x			
		$-Cr^{+6}$ (3 runs)	x			
		-Semi-VOST (3 runs)	x		x	
		-VOST (3 runs)	x		x	
Normal - Only Secondary effluent to Scrubber		-M12S (1 run)	x			
		-Semi-VOST (1 run)	x		x	
		-VOST (2 runs)	x		x	
Site 2						
Steady-State	-M12S (3 runs)	-M12S (3 runs)	x	x	x	x
	-Semi-VOST (3 runs)	-Semi-VOST (3 runs)	x			
	-VOST (3 runs), -PSD (3 runs)	-VOST (3 runs)	x		x	x
Normal	-M12L (3 runs)	-M12L (3 runs)	x	x		
	-Semi-VOST (3 runs)	-Semi-VOST (3 runs)	x		x	x
	-VOST (3 runs)	-VOST (3 runs)	x		x	x
		$-Cr^{+6}$ (3 runs)	x			

[a] M12S = Method 12 Short-Term (approximately 90 minutes sampling time per run); M12L - Method 12 Long-Term (approximately 6-8 hours of sampling time per run; Cr^{+6} = Chromium VI Train; VOST = Volatile Organic Sampling Train; Semi-VOST - Semi-Volatile Organic Sampling Train; PSD = Particle Size Distribution.

[b] Samples which were analyzed for volatile or semi-volatile organics were taken in void-of-air (VOA) vials. Grab samples for metals analysis were taken during each run and composited.

[c] Continuous Emission Monitors (CEMs) for O_2, CO, CO_2, NO_x, SO_2, and total hydrocarbons (THC) were set up at the control device inlet and used for process monitoring during each test day.

included a temporary feed cutoff. At Site 2, normal operation included a feed cutoff, step changes in feed rate, and an increase in sludge moisture content.

SAMPLING AND ANALYTICAL PROCEDURES

Metals and organics samples were collected from the flue gas, sludge feed, scrubber influent and effluent water and bottom ash. In order to relate emissions to incinerator and control device operation, key operating parameters were also monitored.

Quality assurance/quality control (QA/QC) was an integral part of sampling, analytical and data reduction efforts. The QA/QC Project Plan was prepared and approved by EPA prior to the performance of on-site testing. The sampling methods are described briefly below. Additional details are included in the QA/QC Project Plan[2].

Particulate and Metals sampling was conducted at the scrubber inlet/outlet according to EPA Reference Method 12 (Alternate). This method is basically a modification of EPA Reference Method 5 train (Figure 1), with water in the impingers replaced by 0.1 N nitric acid. The particulate/metals samples were collected isokinetically in accordance with EPA Method 5 procedures. After gravimetric analysis of the filters, the particulate was digested in nitric acid and combined with the impinger solutions for analysis. Atomic Adsorption (AA) analysis was used for the determination of arsenic and lead. The determination of beryllium, cadmium, chromium, and nickel was done using the inductively coupled argon plasma (ICAP)technique.

Flue gas sampling for volatile organics was performed using the most recent method developed by EPA[3]. This method, using the volatile organic sampling train or VOST, is designed to collect volatile organic compounds with boiling points between 30°C and 100°C. The organics are collected on two resin traps in series containing Tenax resin and charcoal. The sample is collected at 1 liter per minute for 20 minutes for each pair of traps. Four pair of traps are collected per test run. The resin traps are analyzed by purge and trap followed by gas chromatography/mass spectrometry (GC/MS).

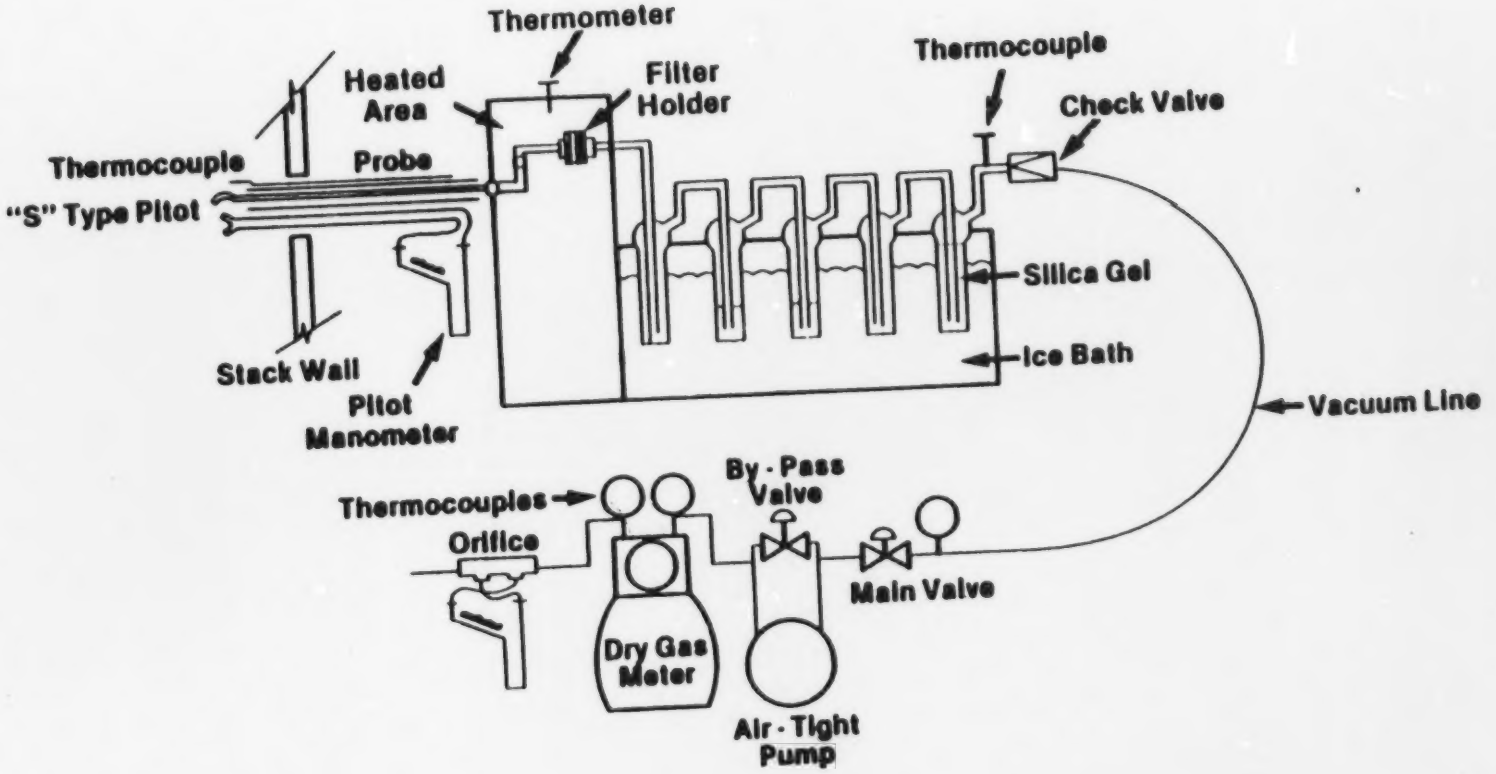

Figure 1. Components of the EPA Method 5 Type Sampling Train.

Semi-volatile samples of the flue gas were collected according to the semi-VOST method developed by EPA[4]. The method is basically a modification of EPA Reference Method 5 with a condenser and adsorbent module added after the filter and before the impinger train to collect semi-volatile organics. The particulate filter, resin trap and impinger solutions are extracted with organic solvent, concentrated, and analyzed by GC/MS.

Sampling for hexavalent chromium was performed using an experimental modified EPA Method 5 train that had no particulate filter and 0.1 N sodium hydroxide in the impingers. Analysis of the samples for both hexavalent and trivalent chromium is then performed by a colorimetric technique. This sampling/analytical approach for hexavalent chromium was not successful due to an interferent present in the final impinger solutions. This interferent apparently formed some type of complex with either the hexavalent chromium or the colorimetric agent. For future testing, a particulate filter will be reinserted in the train.

Grab samples of the process samples which included feed sludge, bottom ash, and scrubber influent and effluent water, were collected at regular intervals during flue gas sampling. The sludge feed was sampled from the feed conveyor after dewatering. Bottom ash was collected from an intermediate point on the conveyor system prior to combination with other ashes. Scrubber water was collected from taps in the pipes. Hourly or 30 minute grab samples were combined at the end of a test run and analyzed following similar analytical schemes used for the flue gas samples.

Key operating parameters monitored included incinerator operating parameters, sludge feed characteristics and wet scrubber system operating data. An example of the specific parameters monitored are included in Table 6. This list was modified on a site-specific basis.

PRELIMINARY RESULTS

Preliminary results from the first two test sites are presented in this section. A comprehensive presentation of all data collected at each site is, of course, beyond the scope of this paper and will be given in

TABLE 6. EXAMPLES OF PROCESS MONITORING DATA

Parameter	Parameter
Incinerator Operating Data	Wet Scrubber System Operating Data
Sludge Feed Totalizer (lb, wet basis)	ΔP (in.H_2))
Hearth Temperatures (^oF)	Scrubber Influent Flow Rate [a] (gpm)
Incinerator Outlet O_2 (by volume)	Scrubber Effluent Flow Rate [a] (gpm)
Shaft Cooling Air Flow and Pressure	Scrubber Inlet Gas Temp (^oF)
Natural Gas Flow Rate (cfm)	Scrubber Outlet Gas Temp (^oF)
Incinerator Draft	
Sludge Feed Characteristics	
Moisture (wt %)	
Volatiles (wt %)	
Heating Value	

site-specific test reports currently being prepared. The focus of this section is on preliminary observations for the effect of operating conditions on metals and organic compound emissions.

At Site 1, four short-term metals tests were conducted under well controlled steady-state operation and an additional three tests were performed over extended periods of "normal" operation. The normal operation tests included transients due to temporary losses in feed, as well as wet sludge operation and step changes in sludge feed rates. Five volatile organics test runs, four at steady state and one under normal operation, were also performed at Site 1. Flue gas samples were only collected at the scrubber outlet.

At Site 2, metals tests conducted included four short-term test runs at steady-state operating conditions and three long-term tests under changing conditions. The process changes were deliberate and included step changes in sludge feed rates, a loss in feed that eventually led to burnout, and operation with wet sludge feed. Six volatile tests were also performed at Site 2. All tests performed at this site included simultaneous scrubber inlet and outlet sampling.

Summary of Metals Emissions

Average metals emission rates for steady state and normal operating conditions that includes transients are presented in Tables 7 and 8 for both test sites. The metals emissions data are expressed in terms of total mass emissions (g/hr) in Table 7 and as emission factors (g of metal emitted/ g of metal fed) in Table 8.

Comparison of scrubber outlet emissions for the two sites shows slightly higher mass emissions at Site 2 for all metals except lead. The higher mass emission rates (Table 7) observed for Site 2 are probably due to the higher total sludge feed rates for this system. Sludge feed rates for Site 2 averaged 7 to 8 ton/hr compared to 5 to 6 ton/hr for Site 1.

TABLE 7. METALS EMISSION RATES FOR DIFFERENT OPERATING CONDITIONS

	AVERAGE MASS EMISSION RATES (g/hr)[a]					
	Site 1 - Scrubber Outlet		Site 2 - Scrubber Outlet		Site 2 - Scrubber Inlet	
Metal	Steady State	Normal	Steady State	Normal	Steady State	Normal
Arsenic	0.06	0.10	0.45	0.53	1.9	2.0
Beryllium	ND	ND[b]	NA	0.001	0.01	0.01
Cadmium	0.39	0.59	2.1	2.5	6.1	6.7
Chromium	0.39[c]	0.32	0.58[d]	0.38[d]	3.6	3.5
Lead	16.6	30.9	5.2	5.9	16.8	26.2
Nickel	0.26[c]	0.20	1.4[d]	1.0[d]	4.1	4.4

[a] Averages based on 4 test runs for steady state operation and 3 test runs for normal operation unless otherwise noted.

[b] Not detected.

[c] Based on 3 valid samples.

[d] Based on 2 valid samples.

TABLE 8. METALS EMISSION FACTORS FOR DIFFERENT OPERATING CONDITIONS

	AVERAGE EMISSION FACTOR (g OF metal/g OF METAL FED)					
	Site 1 - Scrubber Outlet		Site 2 - Scrubber Outlet		Site 2 - Scrubber Inlet	
Metal or Parameter	Steady State	Normal	Steady State	Normal	Steady State[c]	Normal
Arsenic	NA[b]	NA	0.03	0.08	0.22	0.36
Beryllium	NA	NA	NA	0.002	0.03	0.03
Cadmium	0.21	0.31	0.20	0.22	0.55	0.68
Chromium	0.003[c]	0.002	0.005[d]	0.004[d]	0.03	0.04
Lead	0.25	0.43	0.03	0.05	0.13	0.21
Nickel	0.021[c]	0.013	0.008[d]	0.009[d]	0.04	0.05

[a] Averages based on 4 test runs for steady state operation and 3 test runs for normal operation unless otherwise noted.

[b] Not applicable. This particular metal was not detected in either the feed or the combustion gases.

[c] Based on 3 valid samples.

[d] Based on 2 valid samples.

In terms of emissions per gram of metal fed, emissions for Site 1 are either similar or slightly higher (Table 8). The higher emission factors for Site 1 are probably due to the difference in the particulate control systems. Site 1 uses a 3-tray impingement scrubber and Site 2 uses a venturi followed by a 3-tray scrubber. The reason for the considerably higher lead emissions for Site 1 is unclear at this time. Sludge lead concentrations are similar for Site 1 (98 ug/g vs 99 ug/g) and operating temperatures for the two units are similar. The difference in lead emissions may also be related to the types of control systems used.

Comparison of results in Tables 7 and 8 for steady state and normal operation where transients were included show slightly higher metals emission rates for arsenic, cadmium and lead under normal operation. Emissions of beryllium, chromium, and nickel generally show similar emissions for both operating conditions. The difference between steady-state and normal arsenic, cadmium, and lead emissions at the scrubber outlet for the two operating conditions was not found to be statistically significant for either scrubber outlet test based on the Student-t test. The difference between emissions for arsenic, cadmium and lead was significant at the Site 2 scrubber inlet, but only at the 80 percent confidence level. The slight increase in observed emissions may be related to level of operating temperature as discussed in the following section.

Effect of Temperature on Metals Emissions

A comparison of the concentration of metals in flue gas particulates (g of metal/ g of particulate) shows a much more dramatic effect of operating conditions on the characteristics of metals emissions. Data comparing metal-to-particulate ratios for steady and normal operation are presented in Table 9. These data show a consistent and statistically significant trend of metals enrichment for arsenic, cadmium and lead under conditions that included transients at all three test locations.

Comparison of flue gas particulate-to-metals ratios in Table 9 for the scrubber inlet and scrubber outlet at Site 2 shows that particulate leaving the scrubber has a significantly higher concentration of metals. Venturi

TABLE 9. COMPARISON OF PARTICULATE METALS CONCENTRATIONS FOR DIFFERENT OPERATING CONDITIONS

	METALS-TO-PARTICULATE RATIO (ug METAL/ g PARTICULATE)					
	Site 1 - Scrubber Outlet		Site 2 - Scrubber Outlet		Site 2 - Scrubber Inlet	
Metal	Steady State	Normal	Steady State	Normal	Steady State[c]	Normal
Arsenic	12.2	26.9	877	1010	174	223
Beryllium	0.6	0.2	NA	2.1	1.0	1.2
Cadmium	87.2	157	4,150	5,100	557	735
Chromium	42.8[c]	85.3	1,190[d]	803[d]	325	361
Lead	3,720	7,980	8,250	11,560	1,530	2,390
Nickel	62.6[c]	47.0	2,770[d]	1,950[d]	375	539
Temperature:[e]						
Hearth 3	NA[f]	NA	1,382	1,549	1,383	1,550
Hearth 4	1,516	1,499	1,633	1,575	1,610	1,581
Average	--	--	1,507	1,562	1,496	1,566

[a] Averages based on four test runs for steady state operation and three test runs for normal operation unless otherwise noted.

[b] Not applicable. Metal was not detected in flue gas sample.

[c] Based on three valid samples.

[d] Based on two valid samples.

[e] Combustion took place primarily on Hearth 4 for both furnaces.

[f] Not available. The thermocouple for this hearth was found to be inaccurate.

and tray scrubbers are generally less effective at removing finer particulates. Thus, the observed increase in metals concentration for particulate exiting the scrubber indicates that the metals are primarily associated with the finer particulates.

This enrichment of metals on fine particulate may be related to incinerator temperatures. As shown in Table 9, the temperature on the hearth above the combustion hearth averaged higher during the normal tests at Site 2. The effect of temperature on metals enrichment was investigated for the Site 2 data set by plotting metal-to-particulate ratios against temperature for individual test runs under all operating conditions. The temperature used in this analysis was the average of the combustion hearth temperature (hearth #4) and the temperature on the next hearth up (hearth #3).

The results of this investigation suggest that for at least lead, the observed enrichment is related to temperature. Data showing the effect of temperature on lead enrichment in combustion gas particulates is shown in Figures 2 and 3 for the Site 2 scrubber inlet and outlet locations, respectively. The trend of lead enrichment with higher temperatures was found to be statistically significant at the 95 percent confidence level. A similar investigation for the Site 1 data gave inconclusive results because data from the thermocouple on the hearth directly above the combustion hearth is inaccurate.

Data for cadmium are also shown in Figures 2 and 3. Although the least square regression for the cadmium data gives a positive slope, the slope was not found to be statistically greater than zero at the 95 percent confidence level. No temperature effect would be expected for beryllium, chromium or nickel since these metals did not show evidence of enrichment. No temperature effect was found for arsenic either.

Scrubber Removal Efficiencies

Average particulate and metals removal efficiency data for Site 2 are presented in Table 10 for steady state and normal operating conditions. Total particulate removals for the two test conditions are essentially

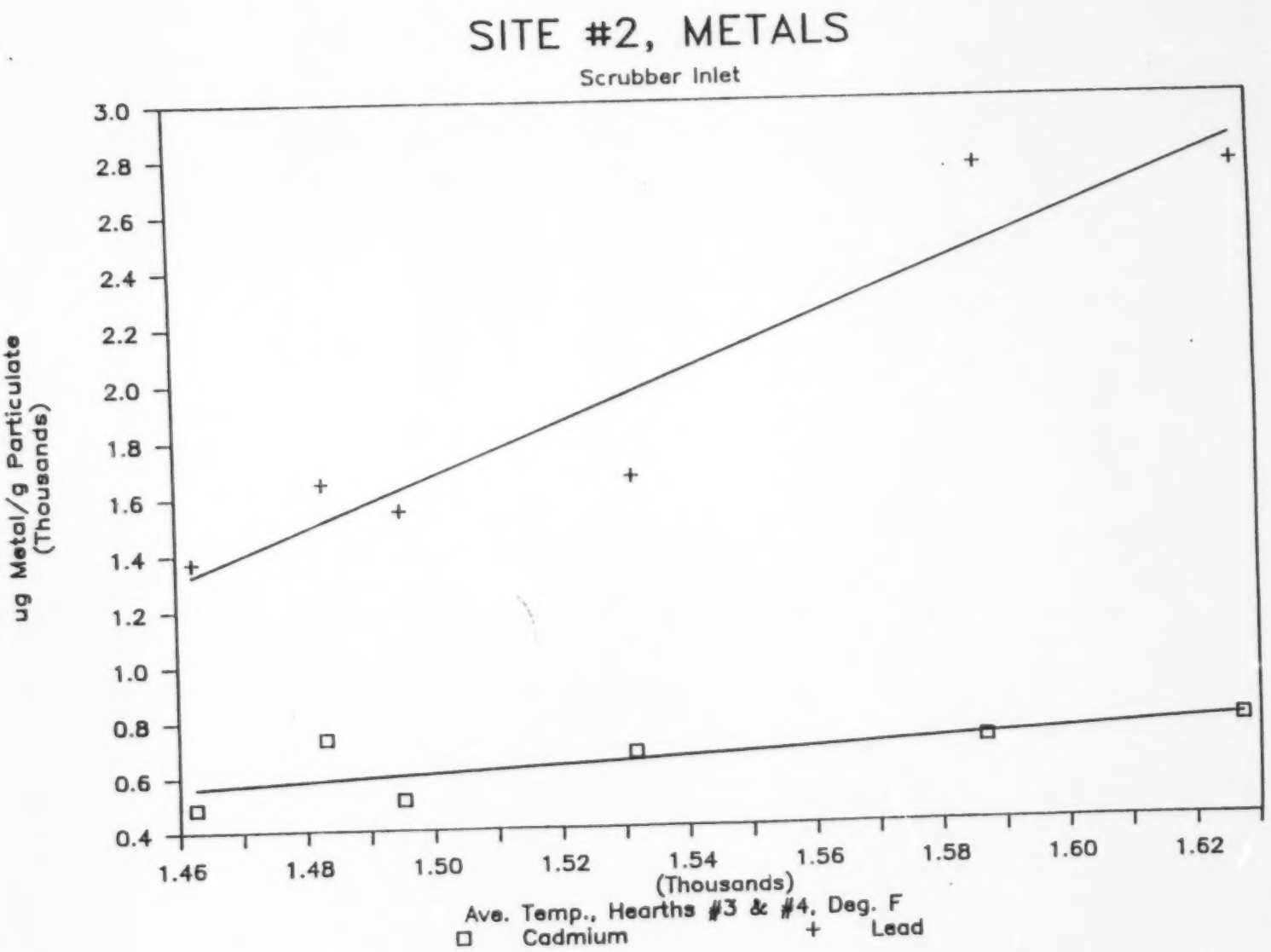

Figure 2. Metal-to-Particulate Ratio versus Average Hearth Temperature at the Site 2 Scrubber Inlet.

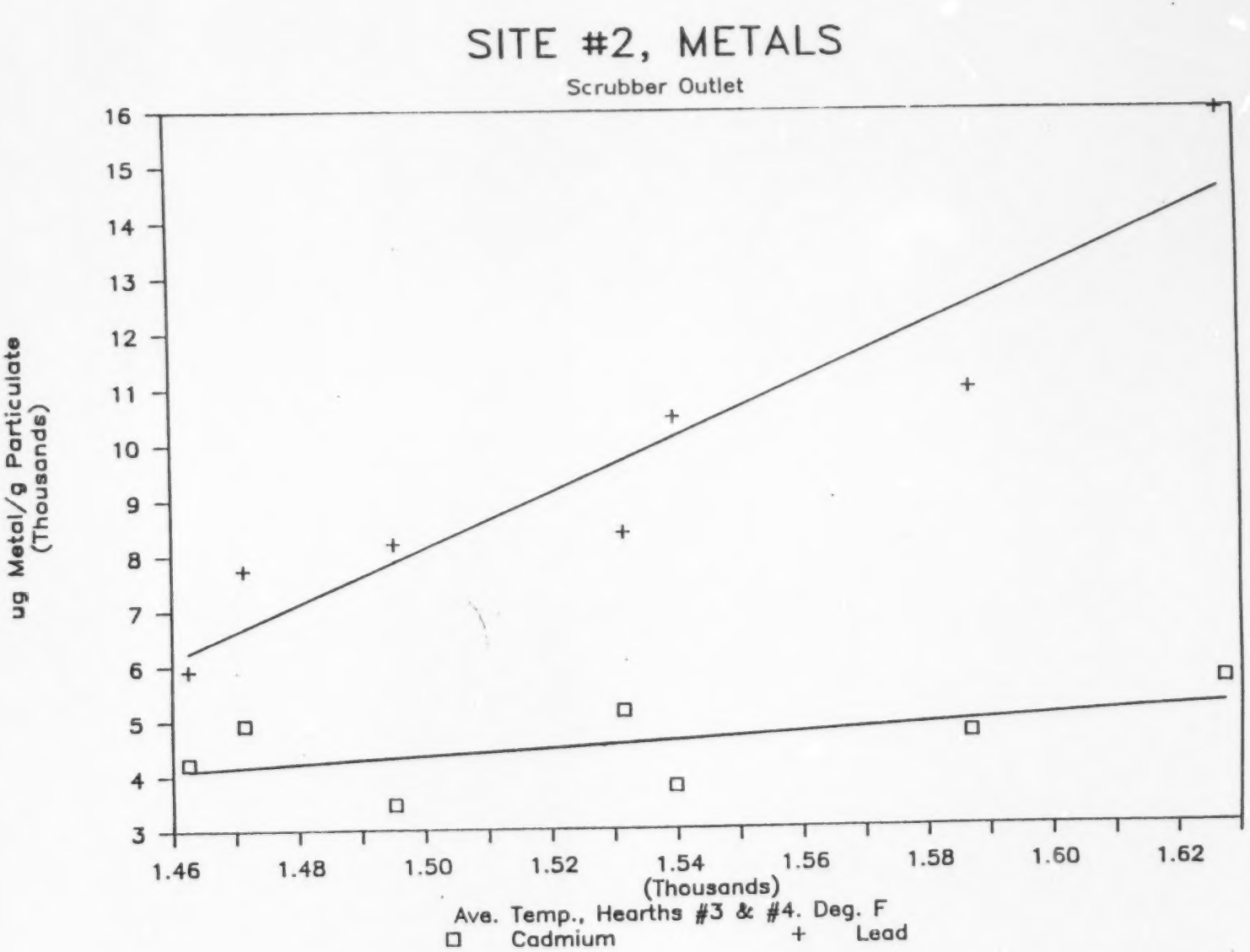

Figure 3. Metal-to-particulate Ratio versus Average Hearth Temperature at the Site 2 Scrubber Outlet.

TABLE 10. METALS/PARTICULATE REMOVAL EFFICIENCIES FOR SITE 2

Metal	Scrubber Removal Efficiency (%)[a] Steady State	Normal
Arsenic	77.2	77.7
Beryllium	NA[b]	87.9
Cadmium	62.8	68.1
Chromium	79.1[c]	90.6[c]
Lead	76.5	78.1
Nickel	53.1[c]	80.3[c]
Total Particulates	95.2	95.4

[a] Averages based on 4 test runs for steady state operation and 3 test runs for normal operation unless otherwise noted.

[b] NA = not applicable. Compound not detected at outlet.

[c] Based on two valid samples.

identical at 95 percent. Removal efficiencies for the metals are similar under both operating conditions, with slightly higher removals seen for chromium and nickel during the normal tests. Efficiencies for these two metals are based on only two valid analyses and, therefore, no statistical comparisons can be made.

Volatile Organic Emissions

Volatile organic compound emissions data for the scrubber outlet at both test sites are presented in Table 11. The target organic compounds shown in the table were determined based on specific compounds of interest to the Office of Water Regulations and Standards and compounds of interest to the Office of Air Quality Planning and Standards and compounds identifies a potential pollutant by combustion testing if the sludge performed at the University of Dayton. All of the target volatile compounds for this program were found in the scrubber outlet flue gas at both test sites except for 1,2 dichloroethane. Comparison of emission rates for the two sites shows slightly higher emissions from Site 1. At both test sites, acrylonitrile, benzene, toluene and vinyl chloride emissions exceeded 5 g/hr. This emission rate is comparable to the mass emission rate observed for lead and cadmium. Volatile organic compounds detected in the sludge feed included: tetrachloroethene and trichloroethene at Site 1 and chlorobenzene, ethylbenzene, methylene chloride, toluene and trichloroethane at Site 2.

Volatile organic compound mass flow rate data for Site 2 are presented in Table 12. Measured values for concentrations of each compound in the sludge and scrubber waters are provided as mass rates wherever the compound was detected. For non-detected volatiles, the mass rate corresponding to the detection limit is provided for comparison with the flue gas emission rates.

The data presented in Table 12 can be used to assess whether the volatile compounds emitted at the scrubber outlet may have come directly from the sludge or if these compounds could be products of incomplete combustion. A review of the mass balance data suggests that acrylonitrile, benzene and vinyl chloride may all be products of incomplete combustion.

TABLE 11. COMPARISON OF VOLATILE EMISSIONS FROM SITES 1 AND 2

VOLATILE COMPOUND	Mass Emission Rate (g/hr)		Emission Factor (g/metric ton)[a]	
	Site 1	Site 2	Site 1	Site 2
Acrylonitrile	13.3	12.6	30.8	14.3
Benzene	16.7	5.3	40.4	5.9
Carbon Tetrachloride	0.10	0.003	0.26	0.003
Chlorobenzene	1	0.36	2.5	0.42
Chloroform	4.8	0.61	12.1	0.71
1, 2-Dichloroethane	0.026	NA[b]	0.06	NA
Trans-1, 2-Dichloroethene	0.20	0.009	0.51	0.01
Ethylbenzene	1.7	0.45	3.7	0.58
Methylene Chloride	2.2	0.58	5.9	0.63
Tetrachloroethene	12.2	0.88	31.9	0.96
Toluene	5	11.9	12.3	14
1,1,1-Trichloroethane	0.29	0.02	0.79	0.024
Trichloroethene	1.4	0.16	3.2	0.18
Vinyl Chloride	5.3	8.0	12.6	8.7

[a] Based on metric tons of volatiles fed during test period.

[b] Not applicable. Compound not detected in flue gas.

TABLE 12. COMPARISON OF AVERAGE VOLATILE ORGANIC COMPOUND MASS FLOW RATES

Volatile Compound	Sludge[a] Feed MDL (mg/hr)	Actual[b] Sludge Feed (mg/hr)	Flue Gas Inlet (mg/hr)	Flue Gas Outlet (mg/hr)	Scrubber[b] Water Influent (mg/hr)	Scrubber[b] Water Effluent (mg/hr)	Scrubber[a] Water MDL (mg/hr)
Acrylonitrile	[12,500]	ND[c]	31,830	12,740	2,240	14,700	[680]
Benzene	[374]	ND	12,450	5,290	ND	ND	[1,500]
Carbon Tetrachloride	[562]	ND	3.8	2.6	ND	ND	[953]
Chlorobenzene	[750]	3,330	365	3.56	ND	ND	[2,040]
Chloroform	[437]	ND	6.3	609	871	ND	[544]
1,2-Dichloroethane	[1,180]	ND	ND	ND	ND	ND	[953]
Trans-1,2-Dichloroethene	[1,440]	ND	7.9	9.0	ND	ND	[102]
Ethylbenzene	[1,620]	10,160	323	445	ND	ND	[2,450]
Methylene Chloride	[1,180]	18,900	1,182	577	1,630	3,080	[953]
Tetrachloroethene	[1,370]	3,590	484	882	ND	ND	[1,390]
Toluene	[1,370]	524,000	19,590	11,920	ND	ND	[2,040]
1,1,1-Trichloroethane	[562]	5,650	4.5	20.1	ND	ND	[1,290]
Trichloroethene	[1,440]	1,350	68.6	157	ND	ND	[646]
Vinyl Chloride	[3,760]	ND	11,620	7,974	ND	ND	[170]

[a] Mass rate calculated as if compound was present at the minimum detection level. Presented for comparison only.

[b] Mass rate calculated based on amounts actually detected in the samples.

[c] Not detected.

The mass rates of these compounds entering with the sludge (at either the actual values or the detectable limits) are much less than the mass rates found at the scrubber inlet. Emission rates for chlorobenzene, ethylbenzene, methylene chloride, tetrachloroethene and toluene are all well below the mass rates of these compounds in the sludge feed.

Review of the Site 2 data in Table 12 for scrubber water and the flue gas outlet stream indicates that 1) acrylonitrile and methylene chloride are scrubbed from the flue gas by the scrubber and 2) chloroform present in the influent water is stripped from the water and emitted in the flue gas.

The results of the semi-volatile tests at Site 2 showed only a few of the target compounds present in the flue gas. These were naphtalene, phenol, and 2-nitrophenol at Site 2 only, and isomers of dichlorobenzene at both sites. Bis (2-Ethylhexyl) Phthalate was also found at both sites in the flue gas, sludge feed, and water samples. However, this particular compound is a contaminant found in plasticizers. The levels found may also have been partially due to sample contamination by plastic containers, etc., listed in sampling and analysis.

SUMMARY

A summary of the preliminary data analysis is as follows:

- Slight increases in average metals emissions is observed for operation that included transients. However, this increase was not found to be highly significant based on statistical tests.

- The concentration of lead in particulates was found to increase with temperature.

- Emissions of volatile compounds from two incinerators were characterized.

- Some of the volatile compounds appear to be products of incomplete combustion.

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